DOCUMENT RESUME

ED 028 063 SE 005 889

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Report of the Action Committee on Bioengineering.

Commission on Education in Agriculture and Natural Reso[illegible]es, Washington, D.C.; Commission on Undergraduate Education in the Biological Sciences, Washington, D.C.

Pub Date Oct 67

Note-14p.; CUEBS Publication No. 21c

EDRS Price MF-$0.25 HC-$0.80

Descriptors-*Biological Sciences, *College Science, Conference Reports, *Curriculum, *Educational Programs, *Engineering, Engineers, Higher Education, Mathematics, Physical Sciences, Specialists, Undergraduate Study

Identifiers-CEANAR, Comm. Education in Agriculture Natural Resources, Comm. Undergraduate Education in Biolog. Sciences, CUEBS

Bioengineering has been defined as "the application of knowledge gained by a cross fertilization of engineering and the biological sciences so that both will be more fully utilized for the benefit of mankind." Bioengineering has at least six areas of application: (1) medical engineering, (2) environmental health engineering, (3) agricultural engineering, (4) bionics, (5) fermentation engineering, and (6) human factors engineering. To fill future needs, bioengineers will specialize in their knowledge of quantitative biology. These engineers will be to the biologist as the electrical engineer is to today's physicists. Recommendations for a four-year undergraduate program in biological and physical sciences and mathematics are presented in this report. A core biology program is discussed and concepts to be included in this core are listed in the appendix. (BC)

Report of the

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CUEBS Publication No. 21c
October, 1967

FOREWARD

In 1965 the Commission on Undergraduate Education in the Biological Sciences (CUEBS) established a Panel on Preprofessional Training in the Agricultural Sciences (PPTAS) to consider the following questions:

(1) What preparation in basic biology, physical sciences and mathematics is desirable for students planning careers in the agricultural sciences?

(2) To what extent can agricultural curricula include the same biology core program taken by other biological science majors?

The panel early recognized that it would be an Herculean task to evaluate adequately all the implications involved in the questions posed, especially when students in such divergent areas (e.g., forestry, wildlife, food science, agricultural engineering, preveterinary medicine) were to be considered. In an effort to obtain the broadest thinking possible, six action committees composed of scientists from universities throughout the country were created in cooperation with the Commission on Education in Agriculture and Natural Resources (CEANAR). Each action committee considered one of the following areas: animal sciences, plant and soil sciences, natural resources, food sciences, bioengineering, social sciences; and each was charged with the responsibility for studying and recommending desirable preparation in the biological sciences and cognate disciplines for undergraduates majoring in the committee's area of specialization. The committees were asked to think in terms of requirements for students who will be professional scientists and agricultural production workers in the 1980's.

The following report is from one of the action committees. The ideas expressed in the report are those of the action committee members and not necessarily those of either of the sponsoring Commissions. The PPTAS position paper itself is available as CUEBS Publication No. 17.

Martin W. Schein
Director, CUEBS

INTRODUCTION

This report was originally designed to study the meaning and value of biology with respect to future education of agricultural engineers. (A secondary goal was to study and recommend desirable instruction in the physical sciences and mathematics.) However, it was soon apparent to the committee that most areas of engineering practice will require some degree of systematic biological knowledge for the fullest measure of service in the years ahead.

It was therefore decided to consider the biological content which might be valuable for all engineering curricula of the near future; in addition, special emphasis was given to those curricula which have a strong biological dimension at present and which will have an even stronger one in the future.

Since 1893 engineering education has been improved and stimulated by a series of distinguished reports and recommendations. These included the Wickenden Report of 1923-29, the Hammond Reports of 1940 and 1944, and the Grinter Report of 1952-55. Currently, the "Goals for Engineering Education" report is under discussion throughout the profession.

None of these reports contains more than passing reference to needs of engineering students for study of biology, although the "Goals" report does indicate that biology should be taught to some engineers and that bioengineering may be an engineering science of the future. Some ignore biology completely, while others assume that a course or two will have been taken in high school, or as a casual college elective.

Thus, it appears that a truly serious examination of the place of biology in engineering education has not been accomplished. To avoid misunderstanding, it must be realized that this present report is not an attempt to present such an examination; it is the hope, however, that this report may stimulate the profession to careful consideration of how biological science might contribute a major component to engineering education of the future.

The Grinter Report states that: "The obligations of an engineer as a servant of society involve the continual maintenance and improvement of man's material environment, within economic bounds and the substitution of labor-saving devices for human effort." The overall, continuing objective of engineering is to modify man's environment and to make this earthly home a better one in the material sense. Engineers have been doing this for countless centuries by purely empirical methods. In fact, engineering technologies long preceded the rise of science and the scientific method.

The 19th and 20th centuries, however, brought training of engineers into the universities and brought science into the training. Now the study of physics and chemistry precedes the design of machines and processes, and with this change has come the rising status of the engineer as a professional who applies scientific principles to solution of human problems. The success of this approach is self-evident. The question is whether the approach is adequate to meet the demands which will be exacted of future engineers.

Up to now, superficial knowledge of human mass, dimension, and capacity for physical force has been adequate for design of vehicles, buildings, roads, bridges, and similar devices. Likewise, systems of food production and waste disposal have been engineered by using only empirical knowledge of macro- and micro- scopic forms of life. It is believed that this era is now coming to a close. As population sharply increases, communications improve and great wars are eliminated, the needs for more complex food-producing systems, increased control of waste products, and rational transportation media (to name a few) will require detailed and precise knowledge of living systems (including man), their response to external stimuli, and environmental tolerances. The empirical methods of engineering interaction with living systems will inevitably be replaced by new forms of science utilized by new kinds of engineers.

This new approach will demand more than a casual acquaintance with the life sciences as future engineers are educated.

The greatest biological problem engineers will face in the future is recognition and definition of the problem itself. This is because the behavior of that which lives is less predictable that that which does not live. Even so, biology is rapidly emerging as a quantifiable science; its premises and parameters are being quantified; therefore, biology is ready to enter engineering education in the way physics was ready 60 years ago. With this in mind, it seems evident that most future problems with which engineers will be concerned will contain a strong biological dimension. Some of these future problems are: (1) the production of an adequate food supply, including development of food sources other than traditional agriculture; (2) the processing, packaging, and transport of food, worldwide, and perhaps interplanetary; (3) maintenance of an adequate water supply; (4) the management of waste and pollution; (5) appropriate uses for land areas; (6) design of new and better structures, vehicles and systems of public transport; (7) provision of engineering service to the biomedical needs; (8) improvement of communications, problem-solving, and data processing systems.

There are, of course, other problems at the engineering-biology interface; many cannot yet be defined, even in such general terms.

This committee therefore recommends that all engineering curricula include much more life science instruction in the near future. Details are discussed later in this report.

Beyond the situation just outlined, there is emerging a class of engineers whose needs for formal biology are more detailed and comprehensive. The word "bioengineer" is widely used to describe these engineers, although its definition is still in the unsteady state.

Bioengineering is being practiced in a broad spectrum. Subcommittee B (Instrumentation) of the Engineers Joint Council, Committee on Engineering Interactions with Biology and Medicine, has defined bioengineering as "the application of knowledge gained by a cross fertilization of engineering and the biological sciences so that both will be more fully utilized for the benefit of man."

Bioengineering has at least six areas of application including:

Medical Engineering - the application of engineering to medicine to provide replacement for damage structure.

Environmental Health Engineering - the application of engineering principles to control the environment so that it will be healthful and safe.

Agricultural Engineering - the application of engineering principles to problems of biological production and to the external operations and environment that influence it.

Bionics - the study of the function and principles of operation of living systems with application of the knowledge gained to the design of physical systems.

Fermentation Engineering - engineering related to microscopic biological systems which are used to create new products by synthesis.

Human Factors Engineering - the application of engineering, physiology, and psychology to the optimization of the man-machine relationship.

At any rate, it can be seen that many, if not most, future problems listed previously will be engaged by persons qualified as bioengineers.

The present generation of bioengineers is largely lacking in formal study of biology. They function quite effectively through sympathetic communication with biological and medical practitioners, and through in-service training and study. This is wasteful, inefficient, and inconvenient. The future bioengineer must have a knowledge of living systems approaching that possessed by professionals in biology.

There are those willing to predict that bioengineering is the next great expansion frontier of engineering. This is based on the reasonable assumption that most future engineering problems will be solved in a biological context of one kind or another. The expanding space program is an example: engineers are now designing closed environments for use far from the earthly home, in territories which are frighteningly hostile to man. These engineering systems are build around the most subtle physiological needs of the human, so that the man and the machine are perfectly adapted to each other. Perhaps some day our automobiles will be designed in a similar fashion.

Many other examples of present and future interactions of engineering with agriculture, biology and medicine could be advanced. However, it is perhaps sufficient to say that we are sure that future graduates, in the next decade or so, will be required to solve problems that are presently ill-defined. Therefore, programs of study should be soundly based on fundamental principles of biological and physical science as well as mathematics. It is deemed of high importance that the biological science be taught from an analytical viewpoint; that is, study of function and mechanism by use of chemistry, physics, and mathematics.

To fill these future needs, some engineers (bioengineers) will be highly specialized and concentrated in their knowledge of quantitative biology. These engineers will be to the biologist as the electrical engineer of today is to the physicist. However, all engineers will be increasingly concerned with biological processes. To facilitate communication across the spectrum of engineering, all engineers will need some training in biological science, and some engineers will need considerable training beyond that.

It is in this framework that the following recommendations are developed.

SUGGESTED BIOLOGICAL SCIENCE INSTRUCTION FOR ENGINEERS

Physiology and ecology should comprise the main foundation in biological sciences for engineers. The emphasis should be placed on the mechanisms of biological systems rather than on the structures.

A biology "core" of one year of 3 or 4 hours per week should be available for engineering students. Additional courses of specialized nature should be available for the third or fourth year to meet the needs of particular engineering fields. The core should be unified and integrated to present, for engineers, a clear and concise view of the unity of function in living systems. Above all, this unity among living organisms should be stressed; it should be the basis of the core; however, diversity among organisms should not be overlooked.

Emphasis should be placed upon the cellular foundations of organisms. The physical-chemical and biological influences of the environment upon every organism should be presented to illustrate the ways in which various organisms meet the challenge of the environment.

The biology core should be preceded by one year of mathematics, one year of chemistry, and taken at least concurrently with physics. Further, it is important that these courses (math and physical science) be used as a basis for teaching the biology courses. Engineers must be challenged in these courses. Some biological science courses are taught to non-science and non-engineering students, who are often lacking in physical sciences and mathematics, thus forcing a descriptive approach. It is emphasized that the student engineers will not be challenged by descriptive teaching methods; they will, however, respond well to a rigorous analytical approach. This may require special courses for students of engineering and physical science.

A general outline of subject matter which the committee believes would constitute a valuable one-year core curriculum in biology for students of engineering is given in Appendix A. Again, emphasis should be placed on unity of function and a quantitative mode of teaching. Some of the suggested topics might be assigned for self-study. Some will have been presented in high school.

The core would serve common interests of most engineering disciplines. Beyond this, interests and needs will diverge considerably. There are not enough similarities in needs or clarity in objectives in each of the engineering fields to identify courses needed by all, beyond the core. At a future date, should more common interests develop (i.e., for the field of bioengineering), additional subject matter for the core should emerge.

At this time, however, additional common requirements for the entire field of bioengineering cannot be identified. Special needs must be met through a flexible system of electives. For example, fermentation engineering requires knowledge of microbiology, medical engineering requires knowledge of anatomy, water and waste treatment requires biochemistry, etc.

RECOMMENDATIONS CONCERNING PHYSICAL SCIENCES

The physical sciences--physics, chemistry and mathematics--are essential to a strong undergraduate program in all areas of engineering; instruction in this area will be offered in the colleges and universities at an increasingly advanced level. However, the comments in this section apply only to curricula in the various areas of bioengineering.

The committee believes that some special preparation in mathematics and physical science beyond that usually expected in an accredited engineering curriculum is needed for fullest comprehension of biological subject matter beyond the core recommended above. Such special preparation would include probability, organic chemistry, modern physics, and perhaps biophysics and biochemistry.

Mathematics

Mathematics is one of the most commonly used and powerful tools of the engineer. It can often be the only link between a problem and a solution for both biological and physical systems. Recommendations of the Committee on the Undergraduate Program in Mathematics have been reviewed.* It is recommended that the proposed basic program of the General Curriculum, consisting of five courses, serve as a minimum for all engineering students preparing for the bioengineering field.

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* The Committee on the Undergraduate Program in Mathematics, P. O. Box 1024, Berkeley, California 94701.

These courses are:

Mathematics 1. Introductory Calculus (3 or 4 semester hours. Prerequisite: Elementary Functions).

Mathematics 2 and 4. Mathematical Analysis (3 or 4 semester hours each. Prerequisite for Mathematics 2: Mathematics 1. Prerequisite for Mathematics 4: Mathematics 2 and 3).

Techniques of one variable, calculus, series, multi-variable calculus, differential equations.

Mathematics 3. Linear Algebra (3 semester hours, Prerequisite: Mathematics 1).

Systems of linear equations, vector spaces, linear dependence, bases, dimension, linear mappings, matrices, determinants, quadratic forms, orthogonal reduction to diagonal form, eigenvalues, geometric applications.

Mathematics 2P. Probability (3 semester hours. Prerequisite: Mathematics 1).

An introduction to probability and statistical inference making use of calculus developed in Mathematics 1.

Variation in the above sequence may arise through differing high school background.

This series of courses varies from the usual engineering requirements by the greater emphasis on linear algebra and inclusion of probability. The latter is considered to be essential for introductory and advanced courses in biological sciences.

Chemistry

The field of bioengineering will rely heavily upon a thorough background in chemistry, including biochemistry, for solution of problems in food processing, storage, waste management, soil and water plant relations, and design of systems for environmental control for humans and animals. In addition to inorganic chemistry, an introduction to the basic concepts of both physical chemistry and organic chemistry is essential. It may be desirable to substitute organic chemistry for analytical chemistry and/or quantitative analysis because of the importance of carbon compounds in biological systems. Topics which will need to be included are the basic laws of chemical combination, equilibrium, oxidation-reduction, energy relationships, reactions as influenced by density, volume and pressure. Laboratory experience is considered essential.

Physics

The physics courses should stimulate the interest of students in the laws of nature, and in the applications of physics to engineering technology. They should familiarize the student with basic principles of both classical and modern physics, which include concepts and techniques that facilitate synthesis, analysis and design by the engineer.

Modern physics is important for the bioengineer because of the increasing interest in atomic and molecular phenomena in the biological sciences.

Concepts that should be included are mechanics, properties of matter, electricity, magnetism, heat, wave motion, sound and light, and atomic and nuclear physics. Laboratory sections for each of these topics are considered desirable. It is expected that a minimum of two semesters of 4 hours each, and more likely 3 semesters, would be required to cover the material. In addition, a course in biophysics would be desirable.

October, 1967
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APPENDIX A

MOLECULAR-CELLULAR BIOLOGY

The Cellular Basis of Biology

<u>Anatomy of the Cell</u> - characteristics of protoplasm

Cellular and Tissue Organization

- Types of cells and tissues
- Unicellular and multicellular organisms
- Origin and differentiation of cells and tissues
- Tissues - organized cells, functional basis

The Chemical and Physical Properties of Protoplasm

- Matter and energy - relate to protoplasm
- Chemical composition of protoplasm
  - Inorganic constituents
  - Organic constituents
- Enzymes and chemical reactions
- Bioenergetics
- Molecules and macromolecules

Physiology and Regulation of Protoplasm: Homeostasis

- Chemical regulation
- Nervous regulation
- Synthesis processes
  - Autotrophic synthesis - photosynthesis
  - Heterotrophic synthesis - microbiological degradation
- Respiration, nutrition and energy dynamics in protoplasm
  - Carbohydrate metabolism
  - Protein and lipid metabolism
  - Secretion and excretion
  - Transport systems

Reproduction and Development

- Cellular reproduction: mitosis-meiosis
  - Asexual vs. sexual reproduction
- Reproductive cycles-environmental influence
- Embryonic development
  - Morphogenesis
  - Regulation and control of development

Heredity

- The chemical basis of heredity - the gene
- Mechanisms of inheritance

Recombination and chromosome mapping
Mutation
Extra-chromosomal genetic systems
Variation in chromosome number
Probability and statistics
Population genetics
Quantitative inheritance
Applied Genetics

Response and Coordination--Behavior

Irritability - stimulus and response
    The nervous system
    Tropisms - response in plants
Innate and learned behavior

ORGANISMIC BIOLOGY

Diversity of Organisms

Non-organisms - viruses
Protists and the microbiological level
Plants, simple to complex
Animals, simple to complex

Physiology

Protist physiology
Plant physiology
    Transpiration - guttation
    Photosynthesis - light, pigments, CO_2 fixation
    Energy transfer
    Respiration; anaerobic - aerobic
    Synthesis and digestion - proteins, fats, carbohydrates
    Plant products - cellulose, lignin, enzymes, vitamins, gums, alkaloids, etc.
    Cellular structure and function in metabolism
    Metabolic pathways
    Conduction of materials through the plant
    Regulation of plant processes
    Mineral nutrition
    Essential elements
    Absorption of minerals
Animal Physiology
    Physico-chemical properties (water, pH colloidal systems)
    Chemical composition of protoplasm
    Stimulus-response concept

Skeleto-muscular system
Skeleto-smooth and heart muscles
The nervous system
Lymphatic system
Digestion, absorption, assimilation, energy and intermediary metabolism
Nutrition
Respiration
Circulation - blood and immunology, cardio-vascular system
Excretion and secretion
Endocrine systems
Lipid, proteins and nucleic acid metabolism

<u>Growth and Differentiation</u>

Plants
- Gametogenesis
- Fertilization
- Morphogenesis: vascular - non-vascular
- Meristems
- Factors influencing growth: external, internal
- Regulation and differentiation
- Types of tissues: meristematic - permanent

Animals
- Gametogenesis
- Organization of the egg - sperm
- Fertilization
- Cleavage and blastulation
- Gastrulation
- Organogenesis
- Tissue interaction - inductions
- Hormones and development
- Human development
- Asexual development
- Regeneration

<u>Morphology</u>

Plants
- Lower organism structure
- Higher organism structure (roots, stems, leaves, seeds, flowers)
- Vegetative phases of non-vascular and vascular plants
- Reproductive phases, vascular, non-vascular

Animals
- Lower organism structure
- Higher organism structure
- Comparative anatomy among selected groups

Reproduction
- Asexual
- Sexual life-cycles
- Endocrine control system

Heredity

- The chemical basis of heredity - the gene
- Mechanisms of inheritance
- Recombination and chromosome mapping
- Mutation
- Extra-chromosomal genetic systems
- Variation in chromosome number
- Probability and statistics
- Population genetics
- Quantitative inheritance
- Applied genetics

ENVIRONMENTAL BIOLOGY

The Ecosystem

- The concept of the ecosystem
- Trophic structure within the ecosystem
- The concepts of habitat and ecological niche
- Biogeochemical cycles (nitrogen, phosphorus, e.g.)
- Food chains
- Energy exchange and flow in ecosystems
- The concept of productivity
- Physical limiting factors (light-temperature-radiation)
- Biological limiting factors (density-predation-competition)

Populations and Communities

- Properties of populations
- Population energy flow
- Population structure
- Density effects
- Rates of growth and death
- Organization at the interspecies population level-interaction between species-predation-parasitism-commensalism-mutalism, etc.
- The concept of biotic community
- Ecological dominance
- Succession, climax, stratification, and periodicity of communities
- Community structure in the past; paleoecology

Habitats

- Fresh water ecology (types of limiting factors-lakes, ponds, lentic communities, lotic communities)
- Marine ecology (types of limiting factors-formation of the sea, quantitative study of plankton, estuarine waters)
- Terrestrial ecology (types of limiting factors-biogeographic regions, structure of terrestrial communities, major terrestrial communities)

Appendix A

Ecology and Human Welfare - application of ecological concepts

Agriculture
Natural resources (conservation, land use, pollution, range management, pond management)
Public health applications (plant and animal population control, biological pest control)
Radiation ecology (waste disposal, the fallout problem, fate of isotopes)
Applications of ecology to human problems (cultural patterns, suboptimal environments, nutrition)

October, 1967
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